Federal Aviation Administration

Airplane Flying Handbook (FAA-H-8083-3B) Addendum

Due to a technical glitch, Chapter 12 of the Airplane Flying Handbook (FAA-H-8083-3B) abruptly ends on page 12-28. The following addendum contains the remaining material that is missing from the current version of the chapter.

Airplane Flying Handbook (FAA-H-8083-3B) Addendum

Chapter 12: Transition to Multiengine Airplanes

Engine Inoperative—Loss of Directional Control Demonstration

An engine inoperative—loss of directional control demonstration, often referred to as a "V_{MC} demonstration," is a task on the practical test for a multiengine class rating. A thorough knowledge of the factors that affect V_{MC}, as well as its definition, is essential for multiengine pilots, and as such an essential part of that task. V_{MC} is a speed established by the manufacturer, published in the AFM/POH, and marked on most airspeed indicators with a red radial line. A knowledgeable multiengine pilot understands that V_{MC} is **not** a fixed airspeed under all conditions. V_{MC} is a fixed airspeed only for the very specific set of circumstances under which it was determined during aircraft certification.

In reality, V_{MC} varies with a variety of factors as outlined below. The V_{MC} noted in practice and demonstration, or in actual single-engine operation, could be less or even greater than the published value, depending on conditions and technique.

Historically, in aircraft certification, V_{MC} is the sea level calibrated airspeed at which, when the critical engine is suddenly made inoperative, it is possible to maintain control of the airplane with that engine still inoperative and then maintain straight flight at the same speed with an angle of bank not more than 5°.

The foregoing refers to the determination of V_{MC} under "dynamic" conditions. This technique is only used by highly experienced test pilots during aircraft certification. It is unsafe to be attempted outside of these circumstances.

In aircraft certification, there is also a determination of V_{MC} under "static," or steady-state conditions. If there is a difference between the dynamic and static speeds, the higher of the two is published as V_{MC}. The static determination is simply the ability to maintain straight flight at V_{MC} with a bank angle of not more than 5°. This more closely resembles the V_{MC} demonstration task in the practical test for a multiengine rating.

The AFM/POH-published V_{MC} is determined with the "critical" engine inoperative. The critical engine is the engine whose failure had the most adverse effect on directional control. On twins with each engine rotating in conventional, clockwise rotation as viewed from the pilot's seat, the critical engine will be the left engine.

Multiengine airplanes are subject to P-factor just as single-engine airplanes are. The descending propeller blade of each engine will produce greater thrust than the ascending blade when the airplane is operated under power and at positive angles of attack. The descending propeller blade of the right engine is also a greater distance from the center of gravity, and therefore has a longer moment arm than the descending propeller blade of the left engine. As a result, failure of the left engine will result in the most asymmetrical thrust (adverse yaw) as the right engine will be providing the remaining thrust. [Figure 12-20]

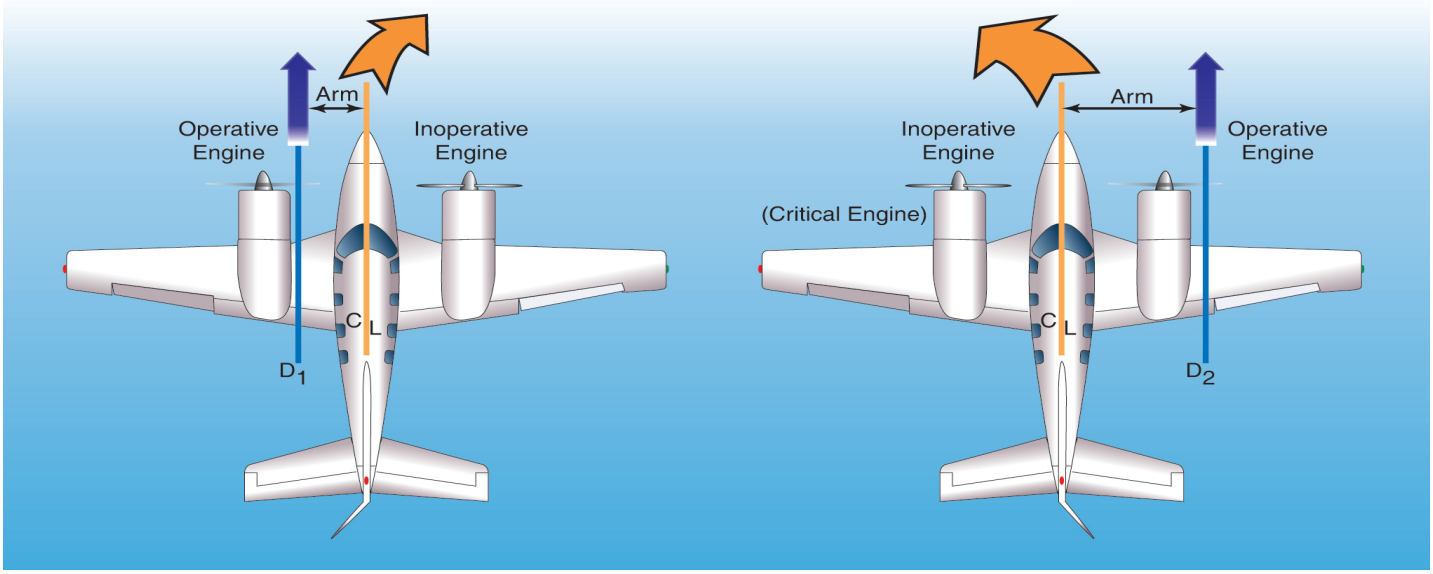

Figure 12-20. *Forces created during single-engine operation.*

Many twins are designed with a counter-rotating right engine. With this design, the degree of asymmetrical thrust is the same with either engine inoperative. No engine is more critical than the other, and a V_{MC} demonstration may be performed with either engine windmilling.

Historically, in aircraft certification, dynamic V_{MC} has been determined under the following conditions:

- **Maximum Available Takeoff Power.** V_{MC} increases as power is increased on the operating engine. With normally aspirated engines, V_{MC} is highest at takeoff power and sea level, and decreases with altitude. With turbocharged engines, takeoff power, and therefore V_{MC}, remains constant with increases in altitude up to the engine's critical altitude (the altitude where the engine can no longer maintain 100 percent power). Above the critical altitude, V_{MC} decreases just as it would with a normally aspirated engine, whose critical altitude is sea level. V_{MC} tests are conducted at a variety of altitudes. The results of those tests are then extrapolated to a single, sea level value.

- **Windmilling propeller.** V_{MC} increases with increased drag on the inoperative engine. V_{MC} is highest, therefore, when the critical engine propeller is windmilling at the low pitch, high rpm blade angle. V_{MC} is determined with the critical engine propeller windmilling in the takeoff position, unless the engine is equipped with an autofeather system.

- **Most unfavorable weight and center-of-gravity position.** V_{MC} increases as the center of gravity is moved aft. The moment arm of the rudder is reduced, and therefore its effectivity is reduced, as the center of gravity is moved aft. For a typical light twin, the aft-most CG limit is the most unfavorable CG position. Historically, 14 CFR part 23 calls for V_{MC} to be determined at the most unfavorable weight. For twins certificated under CAR 3 or early 14 CFR part 23, the weight at which V_{MC} was determined was not specified. V_{MC} increases as weight is reduced. [Figure 12-21]

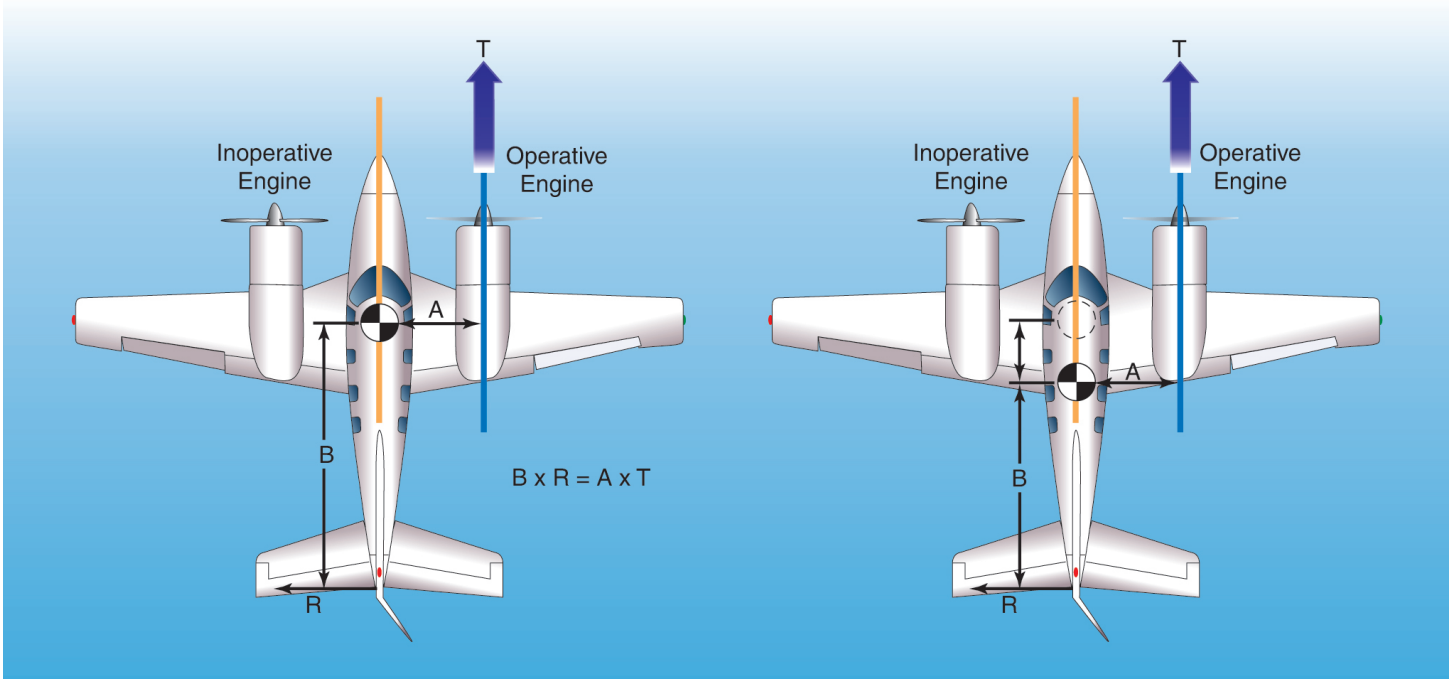

Figure 12-21. *Effect of CG location on yaw.*

- **Landing gear retracted.** V_{MC} increases when the landing gear is retracted. Extended landing gear aids directional stability, which tends to decrease V_{MC}.

- **Wing flaps in the takeoff position.** For most twins, this will be 0° of flaps.

- **Cowl flaps in the takeoff position.**

- **Airplane trimmed for takeoff.**

- **Airplane airborne and the ground effect negligible.**

- **Maximum of 5° angle of bank**. V_{MC} is highly sensitive to bank angle. To prevent claims of an unrealistically low V_{MC} speed in aircraft certification, the manufacturer is permitted to use a maximum of a 5° bank angle toward the operative engine. The horizontal component of lift generated by the bank balances the side force from the rudder, rather than using sideslip to do so. Sideslip requires more rudder deflection, which in turn increases V_{MC}. The bank angle works in the manufacturer's favor in lowering V_{MC} since using high bank angles reduces required rudder deflection. However, this method may result in unsafe flight from both the large sideslip and the need to increase the angle of attack in order to maintain the vertical component of lift.

V_{MC} is reduced significantly with increases in bank angle. Conversely, V_{MC} increases significantly with decreases in bank angle. Tests have shown that V_{MC} may increase more than 3 knots for each degree of bank angle less than 5°. Loss of directional control may be experienced at speeds almost 20 knots above published V_{MC} when the wings are held level.

The 5° bank angle maximum is an historical limit imposed upon manufacturers in aircraft certification. The 5° bank does not inherently establish zero sideslip or best single-engine climb performance. Zero sideslip, and therefore best single-engine climb performance, may occur at bank angles less than 5°. The determination of V_{MC} in certification is solely concerned with the minimum speed for directional control under a very specific set of circumstances, and not the optimum airplane attitude or configuration for climb performance.

During dynamic V_{MC} determination in aircraft certification, cuts of the critical engine using the mixture control are performed by flight test pilots while gradually reducing the speed with each attempt. V_{MC} is the minimum speed at which directional control could be maintained within 20° of the original entry heading when a cut of the critical engine was made. During such tests, the climb angle with both engines operating was high, and the pitch attitude following the engine cut had to be quickly lowered to regain the initial speed. Pilots should understand that attempting to demonstrate V_{MC} with an engine cut from high power, or intentionally failing an engine at speeds less than V_{SSE} creates a high likelihood for loss of control and an accident.

The actual demonstration of V_{MC} and recovery in flight training more closely resembles static V_{MC} determination in aircraft certification. For a demonstration that avoids the hazard of unintended contact with the ground, the pilot selects an altitude that will allow performance of the maneuver at least 3,000 feet AGL. The following description assumes a twin with noncounter-rotating engines, where the left engine is critical.

With the landing gear retracted and the flaps set to the takeoff position, the pilot slows the airplane to approximately 10 knots above V_{SSE} or V_{YSE} (whichever is higher) and trims for takeoff. For the remainder of the maneuver, the trim setting remains unaltered. The pilot selects an entry heading and sets high rpm on both propeller controls. Power on the left engine is throttled back to idle as the right engine power is advanced to the takeoff setting. The landing gear warning horn will sound as long as a throttle is retarded, however the pilot listens carefully for the stall warning horn or watches for the stall warning light. The left yawing and rolling moment of the asymmetrical thrust is counteracted primarily with right rudder. A bank angle of up to 5° (a right bank in this case) may be established as appropriate for the make and model.

While maintaining entry heading, the pitch attitude is slowly increased to decelerate at a rate of 1 knot per second (no faster). As the airplane slows and control effectivity decays, the pilot counteracts the increasing yawing tendency with additional rudder pressure. Aileron displacement will also increase in order to maintain the established bank. An airspeed is soon reached where full right rudder travel and up to a 5° right bank can no longer counteract the asymmetrical thrust, and the airplane will begin to yaw uncontrollably to the left.

The moment the pilot first recognizes the uncontrollable yaw, or experiences **any** symptom associated with a stall, the pilot retards the throttle for the operating engine to stop the yaw as the pitch attitude is decreased. Recovery is made to straight flight on the entry heading at V_{SSE} or V_{YSE}, before setting symmetrical power. The recovery demonstration does not include increasing power on the windmilling engine alone.

To keep the foregoing description simple, there were several important background details that were not covered. The rudder pressure during the demonstration can be quite high. In certification, 150 pounds of force is permitted before the limiting factor becomes rudder pressure, not rudder travel. Most twins will run out of rudder travel long before 150 pounds of pressure is required. Still, it will seem considerable.

Maintaining altitude is **not** a criterion in accomplishing this maneuver. This is a demonstration of controllability, not performance. Many airplanes will lose (or gain) altitude during the demonstration. Remaining at or above a minimum of 3,000 feet AGL throughout the maneuver is considered to be effective risk mitigation of certain hazards.

V_{MC} Demo Stall Avoidance

As discussed earlier, with normally aspirated engines, V_{MC} decreases with altitude. Stalling speed (V_S), however, remains the same. Except for a few models, published V_{MC} is almost always higher than V_S. At sea level there is usually a margin of several knots between V_{MC} and V_S, but the margin decreases with altitude, and at some altitude, V_{MC} and V_S are the same. [Figure 12-22]

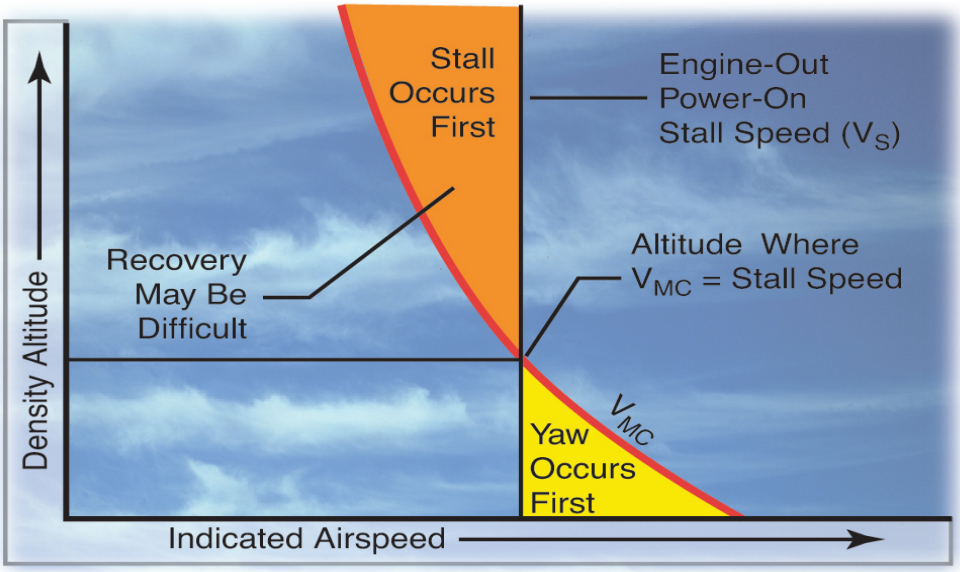

Figure 12-22. *Graph depicting relationship of V_{MC} to V_S.*

Should a stall occur while the airplane is under asymmetrical power a spin entry is likely. The yawing moment induced from asymmetrical thrust is little different from that induced by full rudder in an intentional spin in the appropriate model of single-engine airplane. In this case, however, the airplane will depart controlled flight in the direction of the idle engine, not in the direction of applied rudder. Twins are not required to demonstrate recoveries from spins, and their spin recovery characteristics are generally very poor.

Where V_S is encountered before V_{MC}, the departure from controlled flight might be quite sudden, with strong yawing and rolling tendencies to the inverted orientation, and a spin entry. Therefore, during a V_{MC} demonstration, if there are **any** symptoms of an impending stall such as a stall warning light or horn, airframe or elevator buffet, or sudden loss of control effectiveness; terminate the maneuver immediately by reducing the angle of attack as the throttle is retarded and return the airplane to the entry airspeed. Note that noise within the flight deck may mask the sound of the stall warning horn.

While the V_{MC} demonstration shows the earliest onset of a loss of directional control when performed in accordance with the foregoing procedures, avoid a stalled condition. Avoid stalls with asymmetrical thrust, such that the V_{MC} demonstration does not degrade into a single-engine stall. A V_{MC} demonstration that is allowed to degrade into a single-engine stall with high asymmetrical thrust may result in an unrecoverable loss of control and a fatal accident.

An actual demonstration of V_{MC} may not be possible under certain conditions of density altitude, or with airplanes whose V_{MC} is equal to or less than V_S. Under those circumstances, as a training technique, a demonstration of V_{MC} may safely be conducted by artificially limiting rudder travel to simulate maximum available rudder. A speed well above V_S (approximately 20 knots) is recommended when limiting rudder travel.

The rudder limiting technique avoids the hazards of spinning as a result of stalling with high asymmetrical power, yet is effective in demonstrating the loss of directional control.

To reduce the risk of a loss of control, avoid performing any V_{MC} demonstration from a high pitch attitude with both engines operating and then reducing power on one engine.

Multiengine Training Considerations

Flight training in a multiengine airplane can be safely accomplished if both the instructor and the student are cognizant of the following factors.

- The participants conduct a preflight briefing of the objectives, maneuvers, expected student actions, and completion standards before the flight begins.

- A clear understanding exists as to how simulated emergencies will be introduced, and what action the student is expected to take.

The introduction, practice, and testing of emergency procedures has always been a sensitive subject. Surprising a multiengine student with an emergency without a thorough briefing beforehand creates a hazardous condition. Simulated engine failures, for example, can very quickly become actual emergencies or lead to loss of the airplane when approached carelessly. Stall-spin accidents in training for emergencies rival the number of stall-spin accidents from actual emergencies. The training risk normally gets mitigated by a briefing. Pulling circuit breakers is not recommended for training purposes and can lead to a subsequent gear up landing.

Many normal, abnormal, and emergency procedures can be introduced and practiced in the airplane as it sits on the ground without the engines running. In this respect, the airplane is used as a cockpit procedures trainer (CPT), ground trainer, or simulator. The value of this training may be substantial. The engines do not have to be operating for real learning to occur. Upon completion of a training session, care should be taken to restore items to their proper positions.

Pilots who do not use a checklist effectively will be at a significant disadvantage in multiengine airplanes. Use of the checklist is essential to safe operation of airplanes, and it is risky to conduct a flight without one. The manufacturer's checklist or an aftermarket checklist that conforms to the manufacturer's procedures for the specific make, model, and model year may be used. If there is a procedural discrepancy between the checklist and the AFM/POH, then the AFM/POH always takes precedence.

Certain immediate action items (such as a response to an engine failure in a critical phase of flight) are best committed to memory. After they are accomplished, and as work load permits, the pilot can compare the action taken with a checklist.

Simulated engine failures during the takeoff ground roll may be accomplished with the mixture control. The simulated failure should be introduced at a speed no greater than 50 percent of V_{MC}. If a student does not react promptly by retarding both throttles, the instructor can always pull the other mixture.

The FAA recommends that all in-flight simulated engine failures below 3,000 feet AGL, be introduced with a smooth reduction of the throttle. Thus, the engine is kept running and is available for instant use, if necessary. Smooth throttle reduction avoids abusing the engine and possibly causing damage. Simulation of inflight engine failures below V_{SSE} introduces a very high and unnecessary training risk.

If the engines are equipped with dynamic crankshaft counterweights, it is essential to make throttle reductions for simulated failures smoothly. Other areas leading to dynamic counterweight damage include high rpm and low manifold pressure combinations, overboosting, and propeller feathering. Severe damage or repetitive abuse to counterweights will eventually lead to engine failure. Dynamic counterweights are found on larger, more complex engines—instructors may check with maintenance personnel or the engine manufacturer to determine if their engines are so equipped.

When an instructor simulates an engine failure, the student responds with the appropriate memory items and retards the propeller control toward the FEATHER position. Assuming zero thrust will be set, the instructor promptly moves the propeller control forward and sets the appropriate manifold pressure and rpm. It is vital that the student be kept informed of the instructor's intentions. At this point the instructor may say words to the effect, "I have the right engine; you have the left. I have set zero thrust and the right engine is simulated feathered." Any ambiguity as to who is operating what systems or controls increases the likelihood of an unintended outcome.

Following a simulated engine failure, the instructor cares for the "failed" engine just as the student cares for the operative engine. If zero thrust is set to simulate a feathered propeller, the cowl flap is normally closed and the mixture leaned. An occasional clearing of the engine is also desirable. If possible, avoid high power applications immediately following a prolonged cool-down at a zero-thrust power setting. A competent flight instructor teaches the multiengine student pilot about the critical importance of feathering the propeller in a timely manner should an actual engine failure situation ever be encountered. A windmilling propeller, in many cases, has given the improperly trained multiengine pilot the mistaken perception that the engine is still developing useful thrust, resulting in a psychological reluctance to feather, as feathering results in cessation of propeller rotation. The flight instructor spends ample time demonstrating the difference in the performance capabilities of the airplane with a simulated feathered propeller (zero thrust) as opposed to a windmilling propeller.

Actual and safe propeller feathering for training is performed at altitudes and positions where safe landings on established airports may be readily accomplished if the propeller will not unfeather. Plan unfeathering and restart to be completed no lower than 3,000 feet AGL. At certain elevations and with many popular multiengine training airplanes, this may be above the single-engine service ceiling, and level flight will not be possible.

Repeated feathering and unfeathering is hard on the engine and airframe, and is done as necessary to ensure adequate training. The FAA's Airman Certification Standards for a multiengine class rating contains a task for feathering and unfeathering of one propeller during flight in airplanes in which it is safe to do so.

While much of this chapter has been devoted to the unique flight characteristics of a multiengine airplane with one engine inoperative, the modern well-maintained reciprocating engine is remarkably reliable. When training in an airplane, initiation of a simulated engine inoperative emergency at low altitude normally occurs at a minimum of 400 feet AGL to mitigate the risk involved and only after the student has successfully mastered engine inoperative procedures at higher altitudes. Initiating a simulated low altitude engine inoperative emergency in the airplane at extremely low altitude, immediately after liftoff, or below VSSE creates a situation where they are non-existent safety margins.

For training in maneuvers that would be hazardous in flight, or for initial and recurrent qualification in an advanced multiengine airplane, consider a simulator training center or manufacturer's training course. Comprehensive training manuals and classroom instruction are available along with system training aids, audio/visuals, and flight training devices and simulators. Training under a wide variety of environmental and aircraft conditions is available through simulation. Emergency procedures that would be either dangerous or impossible to accomplish in an airplane can be done safely and effectively in a flight training device or simulator. The flight training device or simulator need not necessarily duplicate the specific make and model of airplane to be useful. Highly effective instruction can be obtained in training devices for other makes and models as well as generic training devices.

The majority of multiengine training is conducted in four-to-six place airplanes at weights significantly less than maximum. Single-engine performance, particularly, at low density altitudes, may be deceptively good. To experience the performance expected at higher weights, altitudes and temperatures, the instructor may occasionally artificially limit the amount of manifold pressure available on the operative engine. Airport operations above the single-engine ceiling can also be simulated in this matter. Avoid loading the airplane with passengers to practice emergencies at maximum takeoff weight since this practice creates an unnecessary training hazard.

The use of the touch-and-go landing and takeoff in multiengine flight training has always been somewhat controversial. The value of the learning experience may be offset by the hazards of reconfiguring the airplane for takeoff in extremely limited time as well as the loss of the follow-through ordinarily experienced in a full stop landing. Touch-and-goes are not recommended during initial aircraft familiarization in multiengine airplanes.

If touch-and-goes are to be performed at all, the student and instructor responsibilities need to be carefully briefed prior to each flight. Following touchdown, the student will ordinarily maintain directional control while keeping the left hand on the yoke and the right hand on the throttles. The instructor resets the flaps and trim and announces when the airplane has been reconfigured. The multiengine airplane needs considerably more runway to perform a touch-and-go than a single-engine airplane. A full stop-taxi back landing is preferable during initial familiarization. Solo touch-and-goes in twins are strongly discouraged.

Chapter Summary

Small multiengine airplanes handle much like single-engine airplanes as long as both engines are functioning normally. A competent multiengine pilot, however, acquires the additional knowledge, risk mitigation strategies, and practical skills required to fly a multiengine airplane in case a loss of thrust from one engine actually occurs. In that case, the pilot will be able to take appropriate action leading to a safe outcome. Much of this chapter discussed loss of directional control. How to obtain the best performance with an inoperative engine was also described in detail. These two considerations correspond to the red radial line (V_{MC}) and the blue radial line (V_{YSE}) on the airspeed indicator. The actions a pilot takes when dealing with stalls, V_{MC}, or best performance vary greatly. Understanding these concepts, knowing how to mitigate the risks, and possessing the skills to handle an engine failure in a variety of situations, allows a pilot to enjoy the increased performance and safety provided when flying a multiengine airplane.